Optical metrology at the Light & Lighting Laboratory: where lighting meets appearance

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The Light & Lighting Laboratory of KU Leuven was established in 1997 by dr. Peter Hanselaer, who, at that time, applied for the first time for funding in order to investigate the spectral absorption and reflection characteristics of photovoltaic cells. Today the research group has expanded and counts about 20 researchers (physicists, engineers, PhD's and doctoral students), and research activities and services to industry are performed in four domains:

- interior lighting (with a focus on energy-efficient applications),
- emerging light sources (quality aspects of (organic) light emitting diodes),
- ray tracing (optical design of luminaires, based on the optical characteristics of light sources, reflectors, and filters),
- visual appearance (metrology of colour and gloss).

At first sight, these four domains might seem to be very diverse. Yet, there is a connecting thread which links all these topics; *optical metrology*. Indeed, accurate optical measurements may yield valuable information for various applications.

In this presentation, an overview of the most important optical metrology facilities available at the Light & Lighting Laboratory will be presented. Besides a description of each device, some practical measurement examples will be discussed. These will highlight the versatility of applications for which every device can be employed, and the new research opportunities that are thereby engendered.

In first instance, the characteristics of 3 near-field goniophotometers will be described. These are primarily employed to determine the luminous intensity distribution (LID) of light sources and luminaires (up to 2 meter diameter) within their photometric limiting distance (the so-called near-field), on the basis of image-resolved measurements by aid of a CCD-camera. Besides the determination of the LID also luminance images and ray data become available, which can further be used to investigate aspects of glare and in ray tracing simulations, respectively.

For a ray tracing simulation to predict the LID and efficiency of the luminaire under development well, not only the ray data of the light source, but also the scattering properties of other components such as reflectors and filters need to be determined accurately. These scattering properties are characterized for any angle of illumination or viewing by the so-called bidirectional scatter distribution function (BSDF). This function offers an entire description of the spatial optical characteristics of any material.

At our laboratory, a measuring instrument which allows for an absolute determination of the spectral BSDF, with a full three dimensional spatial coverage in both reflectance and transmittance mode, a broadband spectral coverage, a large dynamic range, and a reasonable acquisition time has been developed. The major characteristics and capabilities of the instrument will be illustrated with some measurement examples, including the characterization of the transmission properties of dichroic filters and the determination of the colour travel of special effect coatings. The latter suggests that the currently available industrial multi-angle spectrophotometers are not a powerful enough tool to determine and to represent the colour appearance of these newly developed finishes, which have become very popular in the automotive industry, and other markets such as cosmetics.

This highlights the need of new measurement methods and standards in order to ensure reproducibility and traceability of measurements, and in order to quantify appearance attributes (colour, gloss, sparkle, etc.) from optical characteristics in correlation with the evoked visual perception; the so-called *soft metrology* of appearance. To achieve this, the Light & Lighting Laboratory maintains a strong collaboration with multiple European National Metrology Institutes. For instance, in September 2013 the joint research project 'Multidimensional reflectometry for industry' was started up, a research project within the European Metrology Research Programme, implemented by the European Association of National Metrology Institutes (EURAMET).